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# Planted forests and invasive alien trees in Europe: A Code for managing existing and future plantings to mitigate the risk of negative impacts from invasions

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## Abstract

Planted forests of alien tree species make significant contributions to the economy and provide multiple products and ecosystem services On the other hand, non-native trees now feature prominently on the lists of invasive alien plants in many parts of the world, and in some areas non-native woody species are now among the most conspicuous, damaging and, in some cases, best-studied invasive species. Afforestation and reforestation policies, both on public and private land, need to include clearly stated objectives and principles to reduce impacts of invasive trees outside areas set aside for forestry. With the intention of encouraging national authorities to implement general principles of prevention and mitigation of the risks posed by invasive alien tree species used in plantation forestry into national environmental policies, the Council of Europe facilitated the preparation of a *Code of Conduct on Planted Forest and Invasive Alien Trees*. This new voluntary Code, comprising 14 principles, complements existing codes of conduct dealing with horticulture and botanic gardens. The Code is addressed to all relevant stakeholders and decision makers in the 47 Member States of the Council of Europe. It aims to enlist the co-operation of the forest sector (trade and industry, national forest authorities, certification bodies and environmental organizations) and associated professionals in preventing new introductions and reducing, controlling and mitigating negative impacts due to tree invasions that arise, directly or indirectly, as a consequence of plantation forestry.

## Keywords

Biological invasions, environmental management, forest management, invasion pathways, plantation forestry, self-regulation, tree invasions

## Introduction

Planted forests make significant contributions to regional and national economies and provide multiple products and ecosystem services that support livelihoods and biodiversity conservation (Brockerhoff et al. 2008, FAO 2015a, 2015b). However, many widely used forestry trees are invasive – i.e. they spread from planting sites into adjoining areas, and some species cause substantial damage. The challenge is to manage existing and future plantation forests of alien trees to maximize current benefits, while minimising present and future risks, negative impacts and without compromising future benefits and land uses. In many countries or regions, non-native trees planted for production or other purposes often lead to sharp conflicts of interest when they become invasive, and to negative impacts on ecosystem services and nature conservation (Dodet and Collet 2012, van Wilgen and Richardson 2012, Dickie et al. 2014).

A relatively small number of tree species form the foundation of commercial forestry enterprises in many parts of the world. Hundreds of other tree species are widely planted for many purposes, including prevention of erosion and drift sand control, for the supply of fuelwood and other products, for ornamentation, and in various forms of agroforestry (Richardson 2011, Richardson and Rejmánek 2011). As a result, the different forms of forestry have provided very important pathways for the introduction and dissemination of alien trees (Wilson et al. 2009, Richardson and Rejmánek 2011, Donaldson et al. 2014).

Non-native trees now feature prominently on the lists of invasive alien plants in many parts of the world, and in some areas non-native woody species are now among the most conspicuous, damaging and, in some cases, best-studied invasive species. Twenty-one woody plant species feature on the widely cited list of "100 of the World's Worst Invaders" (Lowe et al. 2000), seven woody plants appear on a list of "100 of the worst" invasive species in Europe (Richardson and Rejmánek 2011), and many alien tree and shrubs are black-listed or controlled in Europe, such as *Acer negundo*, *Acacia* spp., *Ailanthus altissima*, *Pinus* spp., *Prunus serotina*, *Quercus rubra* and *Robinia pseudoacacia*. Alien tree species can hybridise and introgress if the species have close relatives in the native flora. This can be undesirable from a conservation point of view (Rhymer and Simberloff 1996, Smulders et al. 2008, Felton et al. 2013, Kjær et al. 2014), especially if the native species are rare in number compared to planted individuals of the introduced tree (Ducci 2014). The impacts of non-native trees generally increase if the species establish themselves and spread in their new environment outside the area of cultivation, but non-native tree species can have impacts even when they are not fully established or widespread (Ricciardi and Cohen 2007, Jeschke et al. 2013, 2014). Indeed, non-native tree species can have impacts as soon as they are introduced. For example, allergic pollen can affect human health, they can act as vectors of new pests or pathogens for other plant species (e.g., Engelmark et al. 2001), they can modify ground vegetation, soil properties and soil fauna (Finch and Szumelda 2007), water balance, fire resilience at the stand level, within areas of their cultivation, relatively fast soon after being planted in new environments (Woziwoda et al. 2014) and over very large areas.

Besides the diverse ecological effects, tree invasions have many complex effects on human livelihoods, both positive and negative. These have been clearly documented in South Africa (especially for Australian *Acacia* and *Prosopis* species) and Papua New Guinea (due to invasion of *Piper aduncum*). *Prosopis* invasions in sub-Saharan Africa have led to considerable rangeland degradation, causing many problems for human societies, especially those relying on subsistence agriculture (e.g., Mwangi and Swallow 2005, Shackleton et al. 2014). In Britain several introduced trees have become "culturally naturalised" (Peterken 2001) causing a change in the perception of nature (Mabey 1996). For example, *Fagus sylvatica* in northern and western Britain is widely accepted by the general public as a native, and *P. sylvestris* is seen as a natural part of the scenery in southern heathlands (Peterken 2001).

To encourage national authorities to implement general principles of prevention and mitigation of the risks posed by invasive alien tree species into their national environmental policies, the Council of Europe has promoted the preparation of a *Code of Conduct on Planted Forest and Invasive Alien Trees* (Brundu and Richardson 2015). The hope is that this Code that provides guidelines focussing on key pathways and core groups will be taken up by relevant sectors of society and eventually be included in national legislation. The Code itself is voluntary and does not replace any statutory requirements under international or national legislation. The Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014, on the prevention and management of the introduction and spread of invasive alien species, does not make any specific reference to the Forest sector as a pathway for plant invasions. On the other hand, it encourages (art. 13) the use of codes of good practice to address the priority pathways and to prevent the unintentional introduction and spread of invasive alien species into or within the Union.

This paper summarises the main features of the traditional and specialised types of plantations that were promoted in the past and that are now important pathways and sources for the introduction and dissemination of alien tree species in Europe. We describe the fourteen principles of the Code of Conduct with a main focus on Europe, while using insights from other regions where relevant to illustrate the evolution of problems and emergence of management approaches. Evidence has accumulated rapidly around the world on the factors that contribute to invasions of alien trees used in different forms of forestry in the past few decades (Richardson et al. 2014). Importantly, insights on the drivers of such invasions have been shown to be, to some extent and with due care, transferable between regions, and countries with recent plantings can learn important lessons from environmentally similar regions in other parts of the world with longer histories of plantings (Richardson et al. 2015).

## Global trends in planted forests

The Food and Agriculture Organisation of the United Nations (FAO) through its Forest Resources Assessments (FRA) has been collating data on forest areas for two

main types of forests: natural forests and forest plantations since 1980. In 2010, the total area of planted forest was estimated to be 264 million ha (about 7% of the total global forest area; FAO 2010a), and this increased to around 278 million ha in 2015 (FAO 2015a, 2015b, Payn et al. 2015). Planted forests by definition comprise trees established through planting and/or through deliberate seeding of native or alien tree species, including the use of clonally propagated materials and genetically modified trees. Establishment is either through afforestation on land previously not classified as forest, or by reforestation of land classified as forest. East Asia, Europe and North America hold the greatest area of planted forests, together accounting for about 75% of global planted forest area, followed by South America and Southern and Southeast Asia (FAO 2010a, Payn et al. 2015). At the global level, non-native tree species grow on about a quarter of the planted forest area (FAO 2010a). More recently, Payn et al. (2015), using FRA 2015 data (FAO 2015a, 2015b), estimated that only between 18% and 19% of the planted forests comprise alien tree species.

Some parts of Europe, particularly in the south, lack highly productive native tree species with timber or growth characteristics suited to plantation forestry, and foresters rely largely upon non-native tree species. These species can be established easily on certain sites, have better growth rates than native species, and have greater physiological adaptability to site conditions, including drought tolerance (Savill et al. 1997). The area dominated by introduced tree species covers about 9.5 million has or 4.4% of the total forest area (excluding the Russian Federation, Forest Europe 2015). In the Russian Federation less than 100,000 ha of its vast forest area was reported as comprising non-native trees (66,000 ha in 2015, FAO 2015a). In Denmark, Iceland and Italy, introduced tree species are reported to occur also on other wooded land (Forest Europe 2011).

## Traditional and specialised types of plantations and introduced tree species in Europe

The most important alien tree species traditionally used in Europe for timber production include *Pseudotsuga menziesii*, *Picea sitchensis*, *Pinus contorta* and other *Pinus* spp., *Larix* spp., *Populus* hybrids and clones, *Robinia pseudoacacia*, *Quercus rubra* and a number of *Eucalyptus* species. Apart from "traditional" types of plantations, that are the most important and widely distributed, alien trees have been used in "specialised" types of plantations (*sensu* Savill et al. 1997, FAO 2010b) and for many other reasons, such as gardening, protective functions, arboreta, erosion protection and for increasing the forest area through afforestation of abandoned or derelict land (Table 1). *Robinia pseudoacacia* has been widely used for purposes such as ornamentation, timber, firewood, re-vegetation of dry land, soil stabilisation and to provide nectar for honey production (EEA 2008). *Ailanthus altissima*, mainly used as an ornamental or for roadside plantings, is one of the most widespread invasive plant species in Europe (Sladonja et al. 2015). *Acer negundo* (Saccone et al. 2010, Erfmeier et al. 2011, Manusadžianas et

**Table 1.** Traditional and specialised types of planted forest (A-G) that are considered in the *Code of Conduct on Planted Forest and Invasive Alien Trees*. The other types (H-L) are not specifically addressed in the *Code*. The most commonly used tree taxa used in each type of forestry are listed in alphabetical order.

| | Type | Main purposes | Alien tree taxa |
|---|---|---|---|
| A | Traditional types of plantations | Timber production, soil protection | *Eucalyptus* spp., *Larix* spp., *Picea sitchensis*, *Pinus contorta*, *Pinus* spp., *Populus* hybrids and clones, *Prunus serotina*, *Pseudotsuga menziesii*, *Quercus rubra*, *Robinia pseudoacacia* |
| B | Plantations on disturbed land | Land reclamation | *Acacia* spp., *Alnus* spp., *Betula* spp., *Eucalyptus* spp., *Pinus* spp., *Salix* spp. |
| C | Short-rotation forestry, Short-rotation coppice | Renewable bioenergy production | *Acacia* spp., *Eucalyptus* spp., *Paulownia* spp., *Populus* spp., *Robinia pseudoacacia*, clonal varieties are interspecific hybrids of *Salix* spp. |
| D | Agroforestry | Wood and non-wood products | *Acacia* spp., *Eucalyptus* spp., *Pinus* spp. |
| E | Arid zone plantations | Preventing and combating desertification | *Acacia* spp., *Azadirachta* spp., *Casuarina* spp., *Eucalyptus* spp., *Gleditsia* spp., *Prosopis* spp. |
| F | Mediterranean plantations and sand dune stabilisation | Soil protection | *Acacia* spp., *Eucalyptus* spp., *Pinus* spp. |
| G | Genetically modified alien trees | Timber production, land reclamation | *Eucalyptus* spp., *Pinus* spp., *Populus* hybrids and clones, *Larix decidua*, *Picea* spp., *Liquidambar styraciflua*, *Castanea dentata*, *Ulmus americana* |
| H | Other types (e.g., roadsides, windbreaks, urban forestry, experimental plots, bee keepers) | Ornamental and multi-purpose | Many species (e.g. *Acer negundo*, *Ailanthus altissima*, *Prunus serotina*, *Robinia pseudoacacia*) |
| I | Botanic gardens and arboreta | Scientific research, education | Many tree species |
| J | Private gardens | Ornamental and multi-purpose | Many tree species |

al. 2014) and *Prunus serotina* (Starfinger 1997, 2010, Starfinger et al. 2003, Pairon et al. 2010, Vanhellemont et al. 2010) are both ranked third and are invasive in several European countries (Forest Europe 2011, 2015).

## Plantations on disturbed land

Numerous industrial processes disturb land of which the principal ones are mining, extraction of sand, gravel and clay, rock and limestone quarries, deposition of waste products including landfill sites, road and railway construction (Savill et al. 1997). The substrate to be reclaimed is almost always derived from mining or earth moving, and it is largely undeveloped subsoil or rock or it is polluted. The nature of reclaimed sites necessitates the use of species which are tolerant of exposure and undemanding nutritionally, characteristics often associated with pioneer species including alien trees (Savill et al. 1997). Non-native plants are widely used for revegetation in many parts of the world (D'Antonio and Meyerson 2002, Li 2006) if they fulfil a temporary successional role to colonize and ameliorate severely degraded sites and facilitate colonization and eventual dominance by native flora (Seo et al. 2008). Species with exceptional physiological tolerances are needed to improve site conditions and initiate soil-forming processes; species of *Acacia*, *Alnus*, *Betula*, *Eucalyptus*, *Pinus*, *Salix* and other pioneers are frequently employed for this purpose (Evans 2009a).

## Short-rotation forestry and short-rotation coppice

Short-rotation forestry is the practice of cultivating fast-growing trees that reach their economically optimum size between eight and 20 years old; each plant produces a single stem that is harvested at around 15 cm diameter. The crops tend to be grown on lower-grade agricultural land, previously forested land, or reclaimed land; they typically do not compete directly with food crops for the most productive agricultural land (McKay 2011). Fast-growing poplars and willows can be cultivated in short-rotation forestry (SRF) cycles of 15–18 years, but in short-rotation coppice (SRC) this is reduced further by cut-back/coppicing at 3–5-year intervals (Karp and Shield 2008).

Of the approximately 400 species of willows, the shrub willows (especially *Salix viminalis* in Europe) are deemed most suitable as bioenergy crops (Kuzovkina et al. 2008). Other species that are used include *S. dasyclados*, *S. schwerinii*, *S. triandra*, *S. caprea*, *S. daphnoides* and *S. purpurea*, and many clonal varieties are interspecific hybrids (e.g. *S. schwerinii* × *S. viminalis*; Karp et al. 2011, Raslavičius et al. 2013). Among poplar species, *Populus nigra*, *P. alba* and their hybrids (e.g., *P. maximowiczii* × *P. nigra*, *P. maximowiczii* × *P. trichocarpa*, *P. trichocarpa* × *P. deltoides*) are most suitable for bioenergy (Karp and Shield 2008, Faasch and Patenaude 2012). Many other alien species, including clones, hybrids and genetically modified trees, are used or are being tested for SRF/SRC, e.g., *Robinia pseudoacacia* in Albania, Italy, Germany,

Hungary and Spain (Grünewald et al. 2009, González-García et al. 2011, Rédei et al. 2011a, Kellezi et al. 2012, Ciccarese et al. 2014), *Acacia saligna* in Israel (Eggleton et al. 2007), and *Eucalyptus* spp. in Portugal (Knapic et al. 2014) and in the UK (Evans 1980, Leslie et al. 2012, Keith et al. 2015).

The European Union has agreed to ambitious targets in terms of renewable energy that will probably promote a dramatic increase in the use of biofuels including short-rotation forestry and short-rotation coppice. This expansion and the continuous search for new species or genotypes may cause several direct and indirect undesired effects on biodiversity, including an increase in the introduction of additional invasive alien tree species into the region (Genovesi 2011).

## Agroforestry

Agroforestry systems include both traditional and modern land-use systems where trees are managed together with crops and/or animal production systems in agricultural settings. Agroforestry is practiced in both tropical and temperate regions, for both wood and non-wood products, including food and fibre for improved food and nutritional security (Jama and Zeila 2005). The potential of agroforestry to contribute to sustainable development has been recognized in international policies, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD), justifying increased investment in its development (FAO 2013). Agroforestry (or "silvoarable agroforestry") has traditionally formed important elements of European and Mediterranean landscapes, has the potential to contribute towards sustainable agriculture in Europe in the future, and it is supported by the Common Agricultural Policy (Eichhorn et al. 2006).

Nevertheless, many agroforestry systems, particularly those that depend on tree planting in or near treeless landscapes, rely heavily on alien plant taxa. As is the case in all endeavours based largely on non-native species, problems arise when these alien trees spread from sites of introduction and cultivation to invade areas where their presence is, for various reasons, deemed inappropriate. In some areas, problems caused by the spread of agroforestry trees from sites set aside for this land use pose a serious threat to biodiversity that may reduce or negate any biodiversity benefit of the agroforestry enterprise (Richardson et al. 2004).

## Mediterranean plantations and sand dune stabilisation

Plantations in the Mediterranean have a long history. In mountainous areas, coniferous plantations were once limited to land at risk from erosion, but these now cover large areas of pastoral land and even agricultural land, either as a result of the establishment of plantations (e.g., *Pinus nigra*) or through colonization of abandoned land. *Pinus radiata* was planted in more than 300,000 has of old fields in Spain during the sec-

ond half of the 20th century, mainly in Atlantic areas. More recently, the species has also been planted in acidic soils of the wet Mediterranean area in former agricultural lands with lime-free soils and annual rainfall exceeding 700 mm (Romanyà and Vallejo 2004). Plantations dominated by pines (*Pinus halepensis*, *P. pinaster*, *P. pinea*) are very common in coastal areas and are increasing in extent, despite an increase in major forest fires. Traditional forest activities (e.g., cork extraction, *P. pinaster* sawmills) have been replaced by multiple uses linked to tourism, hunting, and recreational activities (Etienne 2000).

In Turkey, afforestation with *P. pinaster* was undertaken by the French for the protection of sand dunes around Terkos Lake in 1880 (Deniz and Yildirim 2014). Italian foresters developed successful techniques for stabilizing sand dunes, and as a result of their efforts several thousand hectares of dunes were fixed and afforested in Italy in the 1940s with *Pinus* spp., *Acacia* spp. and *Eucalyptus* spp. (Messines 1952).

## Genetically improved and genetically modified alien trees

Diverse biotechnological methods are being intensively pursued to support plantation forestry with alien trees. These include clonal propagation (e.g., Rédei et al. 2002, 2011a, 2011b), interspecific hybridization, the use of a variety of molecular tools to intensify the selection of superior genotypes (DNA fingerprinting, genome mapping, gene identification and genome sequencing) and transformation (Grattapaglia and Kirst 2008, Strauss et al. 2009). However, of this diverse array of technologies, only transformation, defined by the use of direct modification and asexual insertion of DNA into organisms in the laboratory (that is, genetic engineering or modification), engenders attention from the Convention on Biological Diversity, strong government regulation and controversy over its use, even for research (Strauss et al. 2009).

Traits introduced to genetically modified (GM) trees include modification (quality and quantity) of lignin and cellulose composition, optimised biomass for biofuel production, resistance to pests and diseases, herbicide tolerance, altered growth and reproductive development, among others (Strauss et al. 2009). Hence, GM technology is clearly part of the toolbox for breeding of trees for agriculture and forestry use (Aguilera et al. 2013, Ledford 2014). Ecological risks associated with commercial release range from transgene escape and introgression into wild gene pools to the impact of transgene products on other organisms and ecosystem processes. Evaluation of those risks is confounded by the long life span of trees, and by limitations of extrapolating results from small-scale studies to larger-scale plantations (Frankenhuyzen and Beardmore 2004).

Many tree species are the focus of GM research. Frankenhuyzen and Beardmore (2004) identified 33 species of forest trees that had been successfully transformed and regenerated and additional species are reported by Häggman et al. (2013). Although most field trials have involved *Populus* spp. because of the status of poplar as a model

organism for tree genomics and biotech (e.g., Jansson and Douglas 2007), and most have occurred in the United States, field tests have also been conducted in a number of other tree species and geographies around the world. In Europe 44 confined field trials for *Populus* spp. (30), *Betula pendula* (6), *Eucalyptus* spp. (4), *Picea abies* (2), *Pinus sylvestris* (2) have been approved (Council Directive 90/220/EEC of 23 April 1990, Strauss et al. 2009, Häggman et al. 2013).

## The Council of Europe's policy on invasive alien species and pathways

Founded in 1949, the Council of Europe (CoE) is the oldest European international governmental organisation. It groups together 47 member states, 28 of which are members of the European Union. For almost 50 years, the CoE has been helping to build a set of rules, principles, and strategies related to culture, environment, ethics, and sustainable development (Martin et al. 2013). The CoE has proposed 200 legally binding European treaties or conventions, many of which are open to non-member states on topics ranging from human rights, the fight against organized crime, and the prevention of torture to nature conservation and cultural co-operation. It has also developed many recommendations to governments, setting out policy guidelines with the intention to encourage national authorities to implement these general principles into their national environmental policies (Lasén Díaz 2010, Martin et al. 2013). Importantly, the CoE also promotes actions to avoid the intentional introduction and spread of alien species, to prevent accidental introductions and to build an information system on invasive alien species. Since 1984 the Committee of Ministers of the CoE adopted a recommendation to that effect. Also, the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats), the main Council of Europe treaty in the field of biodiversity conservation, requires its Contracting Parties "to strictly control the introduction of non-native species" (Article 11, paragraph 2.b).

In 2003, the Bern Convention adopted the European Strategy on Invasive Alien Species (Genovesi and Shine 2004), aimed at providing precise guidance to European governments on issues relating to invasive alien species. The Strategy identifies European priorities and key actions, promotes awareness and information on invasive alien species (IAS), strengthening of national and regional capacities to deal with IAS issues, taking of prevention measures and supports remedial responses such as reducing adverse impacts of IAS, recovering species and natural habitats affected. National strategies have been drafted and implemented by many of the Parties following the priorities set in the European Strategy. Many recommendations which specifically addressed invasive alien species and major pathways of introduction have been adopted by the Standing Committee since 1997. The CoE has promoted and supported the preparation of many codes of conducts for pathways, such as the ones on horticulture, botanic gardens, recreational fishing, hunting, protected areas and zoological gardens.

## Target audience for the Code of Conduct

The Code is addressed to all relevant stakeholders and decision makers in the 47 Member States of the Council of Europe. It aims to enlist the co-operation of the forest sector (trade and industry, national forest authorities, certification bodies and environmental organizations) and associated professionals in preventing new introductions and reducing, controlling and mitigating negative impacts due to invasive alien tree species in Plantation Forestry. It complements the *Code of Conduct on Horticulture and Invasive Alien Plants* published by the Council of Europe (Heywood and Brunel 2009, 2011) aimed at the horticultural industry and trade and the *European Code of Conduct for Botanic Gardens on Invasive Alien Species* (Heywood and Sharrock 2013). These three codes should also be considered by private or public gardens or arboreta in Europe with major collections of alien trees that are not considered forest plantations in the narrow sense. The Code is voluntary and does not replace any statutory requirements under international or national legislation but should be seen as complementary to them, and to general policies such as the *State of Europe's Forests 2015* report, and as a soft-law standard (Hickey et al. 2006, MacKenzie 2012, Terpan 2015). Although voluntary, it is important that such as many stakeholders as possible should adopt the good practices outlined in this Code so as to reduce the likelihood of compulsory legislation having to be introduced should self-regulation fail. Private forest enterprises and public forest managers may wish to publicize their adherence to the Code through adopting a symbol or logo indicating this. Some of the principles of this Code could become part of forest certification schemes and sustainable forest management criteria and indicators.

To be fully effective and to increase the likelihood of a long-term behaviour change, a voluntary Code should be widely disseminated and translated into national languages. A straightforward example is provided for by the implementation of the Code of Conduct on invasive alien plants in Belgium during the AlterIAS LIFE+ project (Halford et al. 2014). National authorities should acknowledge that the issue of invasive alien trees is a major threat for species, habitats and ecosystems, and undertake measures to ensure that all the available legislation established to prevent introductions of invasive species from forestry is fully understood, and effectively transposed, implemented and enforced. National authorities should develop strategies and protocols for dealing objectively with conflicts of interest between those who benefit from the introduction, dissemination and cultivation of alien trees, and those who perceive, and are affected by, negative impacts of these invasion alien trees.

## The principles of the Code of Conduct on planted forest

The fourteen principles of the Code of Conduct are clustered in five groups: (1) Awareness; (2) Prevention & Containment; (3) Early Detection & Rapid Response; (4) Outreach; (5) Forward Planning. They are the following:

1.1 Be aware of regulations concerning invasive alien trees;
1.2 Be aware of which alien tree species are invasive or that have a high risk of becoming invasive, and of the invasion debt;
1.3 Develop systems for information sharing and training programmes;
2.1 Promote – where possible – the use of native trees;
2.2 Adopt good nursery practices;
2.3 Modify plantation practices to reduce problems with invasive alien tree species;
2.4 Revise general land management practices in landscapes with planted forests;
2.5 Adopt good practices for harvesting and transport of timber;
2.6 Adopt good practices for habitat restoration;
3.1 Promote and implement early detection & rapid response programmes;
3.2 Establish or join a network of sentinel sites;
4.1 Engage with the public on the risks posed by invasive alien trees, their impacts and on options for management;
5.1 Consider developing research activities on invasive alien trees species and becoming involved in collaborative research projects at national and regional levels;
5.2 Take global change trends into consideration.

Table 3 summarizes the relationship between the plantation cycle and the fourteen principles. The concepts of awareness, prevention, early detection and rapid response, outreach and forward planning are also also in the *Code of Conduct on Horticulture and Invasive Alien Plants* and in the *European Code of Conduct for Botanic Gardens on Invasive Alien Species*, but most of the principles of the *Code of Conduct on Planted Forest and Invasive Alien Trees* are significantly different. This is due, for example, to the large extent of many planted forests, which are often present in very fragile ecosystems, and to the fact that planted forests make significant contributions to regional and national economies and provide multiple products and ecosystem services that support livelihoods and biodiversity conservation.

**1.1 Be aware of regulations concerning invasive alien trees.**

Those engaged in the planted forest sector need to be aware of their obligations under regulations and legislation. The Regulation (EU) no. 1143/2014, the Plant Health Directive 2000/29/EC, the Wildlife Trade Regulations (338/97/EC and 1808/2001/EC) and the Habitats Directive (92/43/EEC) only apply to the 28 member countries of the European Union. Many other international conventions addressing issues of invasive alien species have been ratified by European and Mediterranean Countries (Shine 2007, Srivastava 2011, Table 2). At the national (or subnational) level, some countries have legislation and/or regulations aimed at preventing possession, transport, trade or release in the wild of specific invasive alien trees (Suppl. material 1). For example, in Norway, the 2005 white paper on the Government's environmental policy and the state of the environment in Norway (Report No. 21 – 2004-2005 - to the

**Table 2.** The main international legal instruments relevant to planted forests and invasive alien plants. The list includes both hard- and soft-law (the latter being quasi-legal instruments without legal binding force).

| Legal instrument | Relevance to plantation forestry |
|---|---|
| Convention on Biological Diversity (CBD) | The Convention made numerous decisions with respect to alien species, many of which are directly relevant to the management of alien tree species. In particular, the COP 11 Decision XI/19. |
| International Plant Protection Convention (IPPC) | It aims to prevent the introduction and spread of plant pests. The aim of the CBD to prevent the introduction of alien species corresponds in large measure to the aim of the IPPC. |
| European and Mediterranean Plant Protection Organisation (EPPO) | The alien trees *Acacia dealbata*, *Ailanthus altissima* and *Prunus serotina* are listed in the EPPO list of invasive alien plants. |
| The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) | It primarily addresses trade in endangered species, can prevent or better regulate the transfer of endangered species that may be invasive. *Araucaria araucana* and *Dalbergia nigra* are included in Suppl. material 1. |
| CoE / Bern Convention | The Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats), the main Council of Europe treaty in the field of biodiversity conservation, requires its Contracting Parties "to strictly control the introduction of non-native species". In 2003, the Bern Convention adopted the European Strategy on Invasive Alien Species and since 1997 many Recommendations on invasive alien species have been adopted by the Standing Committee. |
| Sustainable Forest Management | Statement of Principles for the Sustainable Management of Forests was adopted in 1992 at the Earth Summit in Rio in response to global concerns about forestry practices and the exploitation of natural forests. |
| Forest Certification | Most certification standards refer to the use of appropriate provenances, varieties and species for afforestation and reforestation. Native species are always preferred, but alien species are allowed where they are substantially superior to indigenous species for reaching plantation objectives (Stupak et al. 2011) or as long as negative impacts can be avoided or minimized. |
| Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora | According to Article 22.b, in implementing the provisions of this Directive, Member States shall: "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction. |
| Plant Health Regime in the European Union | The introductions of some tree species might be restricted or specifically regulated due to phytosanitary reasons |
| Biodiversity Strategy of the European Union | The Target 5 of the EU Biodiversity Strategy requires that "by 2020 Invasive Alien Species (IAS) and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new IAS". Action 16 of the Target 5 commits the EU to a dedicated legislative instrument on the issue. |

| Legal instrument | Relevance to plantation forestry |
|---|---|
| EU Regulation on Invasive Alien Species | This instrument seeks to address the problem of invasive alien species in a comprehensive manner so as to protect native biodiversity and ecosystem services, and to minimize and mitigate the human health or economic impacts that these species can have [Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species]. |
| EU Forestry Policy and CAP | Council Regulation (EEC) no. 2080/92 of 30 June 1992 instituted a Community scheme of aid for forestry measures in agriculture. It was intended to promote the reforestation of agricultural land also with the use of alien trees (e.g. *Eucalyptus* spp. and *Robinia pseudoacacia*). |
| EU Energy Policy | The European Union's Renewable Energy Strategy (Directive 2009/28/EC) calls for 20% of the EU's final consumption of energy to be from renewable energy sources by 2020. This instrument thus promotes the planting of alien trees, as biomass from short-rotation coppice and short-rotation forestry has the potential to contribute significantly to Europe's targets for enewable energy. |

**Table 3.** The main phases and activities of a forest plantation cycle and their relationships with the principles of the *Code of Conduct on Planted Forest and Invasive Alien Trees*. The fourteen principles are clustered in five groups: (1) Awareness; (2) Prevention & Containment; (3) Early Detection & Rapid Response; (4) Outreach; (5) Forward Planning.

| Forest activity / operation | Code Principles | Operational goals and exemplifying actions |
|---|---|---|
| Site and location assessment and selection | **1.1** | Decision-support schemes and research findings should be applied to identify the most appropriate sites for cultivation of alien trees within landscapes; biodiversity issues and ecosystem services must be always considered in plantation design and site selection. |
| Species and provenances selection | **1.1, 1.2, 2.1** | The use of native species or non-invasive alien or less-invasive alien tree species as alternatives for highly invasive alien species in plantation forestry should be always considered. |
| Risk assessment | **1.2, 5.2** | Risk assessments are available for many alien tree species, e.g. for *Ailanthus altissima* and many *Acacia* spp. It is important to incorporate climate change into risk models for an anticipatory evaluation of scenarios for invasiveness of alien trees. |
| Plantation design | **1.2, 2.3** | Containment of alien trees to areas set aside for their cultivation must become an integral part of silviculture and must be incorporated in best-management practice guidelines and certification schemes. |
| Plantation roads | **2.3, 2.4, 2.5** | Plantation roads and tracks should be designed and managed to a standard capable of carrying anticipated traffic with reasonable safety while minimising impacts on environmental and cultural values, and to reduce the risk of acting as corridors for dispersal of invasive trees. Where revegetation is used to stabilise fills or embankments, the species must be suitable for the site and where possible native to the area. |
| Site preparation | **2.3, 2.4** | Plantation establishment and maintenance activities should be appropriate for successful tree establishment and growth and be undertaken with care for the protection of environmental and cultural values and immediate neighbouring land uses. Site preparation activities should be appropriate for successful tree establishment and growth, whilst minimising potential adverse environmental impacts. |
| Nursery, plantation establishment and restocking | **2.2** | The overall objective should be to produce suitable planting stock, which may include seedlings, cuttings and wildlings. Planting stock should also be potentially able to restore biodiversity (requiring a range of native species and reliable identification and labelling). Native alternatives to invasive tree species should be produced. The nursery industry should be proactive in their approach to stop producing and selling potentially invasive species and by developing best-management practices for invasive tree species in stock. |
| Fertilizing | **2.4** | Fertiliser and chemicals should be used only where appropriate to the site conditions and circumstances and with care for the maintenance and protection of water quality, biodiversity, soil values and neighbouring land uses. |
| Weeds, pest & disease control | **2.4** | Forest protection measures should be taken to minimise the impact of damage agents on plantations and surrounding assets, lands and communities. |

| Forest activity / operation | Code Principles | Operational goals and exemplifying actions |
|---|---|---|
| Spacing, thinning, pruning and rotation length | **2.3, 2.4** | Forest plantation owners should be aware of activities that favour the spread of invasive alien tree species. For example, coppicing was found to be a driver of the invasion by *Ailanthus altissima* and *Robinia pseudoacacia*. |
| Timber harvesting | **2.4, 2.5** | Timber harvesting must be conducted legally and safely, and be managed to minimise the impact of harvesting operations on environmental and cultural values. This includes felling operations, processing and extraction, log landing and processing sites localisation and management. |
| Regeneration | **1.2, 2.4** | Silvicultural methods for regeneration must suit the ecological requirements of the forest type, taking into consideration the requirements of sensitive understorey species and local conditions. |
| Environmental (biodiversity) and cultural values in plantations | **1.2, 2.1, 2.3, 2.4** | Significant environmental and cultural values should be considered at all stages and adverse impacts minimised by appropriate planning and management. Biological diversity and the ecological characteristics of native flora and fauna within forests are maintained. |
| Soil & water | **1.2, 2.3, 2.4** | Soil and water assets within forests must be conserved. River health must be maintained or improved, soil, waterways and aquatic and riparian habitats should be protected from disturbance. Waterways may act as corridors for secondary invasions. |
| Fire prevention, suppression, prescribed fire | **2.4** | Fire may promote or suppress invasive tree populations. Invasive tree populations may also alter fire regimes The risk of promoting the spread of fire-tolerant or pyrophytic alien trees must be taken into account when planning the use of prescribed burning in plantation forests. |
| Research & development | **1.3, 3.1, 5.1, 5.2** | Plantation forestry must be supported by R&D, e.g., revisit as many sites as possible in Europe where many alien tree species were planted long ago, and global-change trends must be considered. |
| Plantation Management Plan | **1.3, 2.3, 2.4, 2.5** | Plantation management plans (PMPs) should incorporate strategies for alien outbreaks. PMPs should be prepared prior to operations and should demonstrate how the principles of environmental care, cultural heritage maintenance and fire protection objectives will be achieved, taking into account the presence in the plantation of alien trees, accounting for the scale, intensity and risk associated with an operation. PMPs should be revised at appropriate intervals or in response to changed circumstances. |
| Monitoring, Early warning and rapid intervention | **1.2, 1.3, 3.1, 3.2** | Forest [plantation] health should be monitored and maintained by employing appropriate preventative, protective and remedial measures. Alien tree wildings are relatively easy to control only in the very early stage of invasion. |
| Restoration | **1.2, 1.3, 2.6, 5.1** | Specific guidelines are needed for the restoration of sites previously occupied by plantations with alien trees. Forest and restoration managers need to understand the competitive role that native and alien tree species have in the regeneration dynamics of plantations and how this might be manipulated to favour native forest regeneration. |
| Legislation Framework relevant to PF and IAS | **1.1** | Must comply with all laws and accepted principles for sound plantation management and issues relating to invasive alien species. |
| Certification schemes and voluntary codes | **1.1** | Native species are always preferred in certification schemes, but alien species are allowed where they are clearly superior to indigenous species for reaching plantation objectives, as long as negative impacts can be avoided or minimized. |

| Forest activity / operation | Code Principles | Operational goals and exemplifying actions |
|---|---|---|
| Stakeholder mapping and participation | **1.2, 1.3, 3.1, 4.1** | Planted forests and control methods must actively engage with affected stakeholders and be supported by appropriate communication and complaint-management strategies. For example, public-participation GIS and related tools can generate spatial information for a variety of urban, regional, and environmental planning applications. |
| Outreach | **1.2, 1.3, 3.1, 4.1** | The general public is one of the most important stakeholder groups in national issues of forests and forestry and must be kept informed. |
| Safety and Training | **1.2, 1.3, 3.1** | Establishment, management and harvesting activities must be conducted in a safe and responsible manner by trained operators who have the skills, knowledge and tools relevant to the activity being undertaken. |

Storting), the new Forestry Act (Act of 27 May 2005, no. 31, relating to forestry), the Nature Diversity Act (Act of 16 June 2009, no. 100), the Regulation on non-native trees (Regulation of 15 March 2013, no. 284), the national Strategy on Invasive Alien Species (published in May 2007) and the Norwegian Black List (Gederaas et al. 2012), are the main national specific documents referring to non-native trees. The Guidelines on trees, shrubs and plants for planting and landscaping in the Maltese Islands limit the use of alien trees in afforestation projects on agricultural land (MEPA 2002). The Iceland Forest Service has put forth a set of guidelines to afforestation planners: planting of aliens trees within natural woodlands is discouraged (Gunnarsson et al. 2005). Planting in treeless land must be carefully assessed considering the phenomenal and unique importance of the Icelandic breeding waterfowl populations which are at risk from the forestry. The Swedish Forestry Act placed restrictions on the planting programme of *Pinus contorta* in 1987, 1989 and 1991 due to extensive infection by *Gremmeniella abietina* in high elevation areas in northern Sweden after periods of extreme weather conditions from 1984 to 1987 (Karlman 2001).

### 1.2 Be aware of which alien tree species are invasive or that have a high risk of becoming invasive, and of the invasion debt.

Over 430 alien tree species worldwide are known to be invasive, and the list is growing as more tree species are moved around the world and become established in novel environments (Rejmánek and Richardson 2013, van Wilgen and Richardson 2014). Increasing awareness of problems associated with invasive forestry trees means that information on invasive species and ways of dealing with them is becoming more easily accessible - on the Internet, in scientific and popular publications, and via special interest groups. Ignorance is no longer an excuse for disseminating invasive alien trees (Richardson 2011). Global lists of invasive alien trees are available (Richardson and Rejmánek 2011, Rejmánek and Richardson 2013). "Invasive elsewhere" is one of the most robust predictors of invasiveness in trees, and there is strong evidence that species replicate invasive behaviour in environmentally-similar conditions in different parts of the world (Wilson et al. 2011).

The fact that some alien forestry trees have not yet spread from given planting sites should not be taken as evidence that invasions will not occur in the future. Experience with the same species in other parts of the world, including areas where the species have long residence times, should be evaluated to assess the extent of "invasion debt" (Richardson et al. 2015; Rouget et al. 2016).

Some countries have national or sub-national black lists (Suppl. material 1), identifying those alien species whose introduction is prohibited or discouraged due to their potential adverse effects on the environment or human, animal or plant health. Alien tree species that appear on black-lists should not be used for new plantations. An alternative approach used in other countries relies on a "white list" approach (or red, green and amber, see Perrings et al. 2005, Simberloff 2006) for identifying alien species that

pose low invasion risk. Both listing systems have pros and cons (Simberloff 2006). For example, black-lists should only be considered as guides and one should not assume that non-listed alien tree species are safe. Additionally, in a huge country the translocation of a species from one part to another is just as likely to lead to invasions as are trans-continental introductions. For this reason, Notov et al. (2011) propose the adoption of three-level system of sub-national lists called "black books" for Russia.

Nevertheless, lists offer a useful approach for both companies and government agencies and could be used to fast-track approval of species or to reduce liability for forest owners when using low-risk non-native trees for plantations. Only in a few European countries are such lists supported by dedicated legislation (Essl et al. 2011); in other cases they are not legally binding even if scientifically sound, with priorities based on a rigorous risk assessment process. There are over 100 risk assessment models for invasive plant species (Leung et al. 2012), with some decision schemes developed specifically for trees or woody plants (Reichard and Hamilton 1997, Pheloung et al. 1999, Haysom and Murphy 2003, Widrlechner et al. 2004, Křivánek and Pyšek 2006, Gordon et al. 2011, 2012, Kumschick and Richardson 2013, Wilson et al. 2014). At the same time, only a few risk assessment methods are in line with the requirements of the Regulation (EU) No 1143/2014 (Roy et al. 2014).

### 1.3 Develop systems for information sharing and training programmes.

The efficacy of any strategy to address invasive alien trees, including the capacity to produce reliable risk assessment reports (see *principle* 1.2), depends on the available information, and on the sharing of data, knowledge and experience. Information sharing systems would greatly improve the ability of authorities to prevent the introduction and spread of invasive tree species (e.g., Katsanevakis et al. 2014). Also, invasive species management requires specialist knowledge and skills which can only be developed over time. The capacity and awareness of land owners, forestry officials and other stakeholders are crucial for the effective implementation of the principles of the Code. There is a need to strengthen training institutions and to revisit the training curricula of forestry personnel and other stakeholders in silviculture, species and provenance identification, reduced impact logging, resource assessment, and in the management of both natural forests and non-native tree plantations.

### 2.1 Promote – where possible – the use of native trees.

The use of native species or non-invasive alien or less-invasive alien tree species as alternatives for highly invasive alien species in planted forest should be always considered (Richardson 1998, FAO 2010c, Gordon et al. 2012, Lorentz and Minogue 2015, Peltzer at al. 2015), as should the precise provenance of seeds and germplasm (Aarrestad et al. 2014). For example, Lorentz and Minogue (2015) remark that trait selection during breeding is

potentially a very effective containment approach for managing *Eucalyptus* invasion risk. The likelihood of spread can be reduced by decreasing fecundity or by increasing the age to maturity, although the later method may negatively influence productivity (Gordon et al. 2012). This strategy has been successfully implemented in other taxonomic groups, including a triploid *Leucaena* hybrid in Hawaii (Richardson 1998). Likewise, elimination of seed production is thought to be a feasible goal for *Eucalyptus* (Gordon et al. 2012), and elimination of fertile pollen production has already been accomplished in the transgenic hybrid *E. grandis* × *E. urophylla* (AGEH427) (Hinchee et al. 2011). Ensuring containment of genetically modified trees through sterility could be significant because it eliminates the need for costly, uncertain and complex ecological research to understand and predict the impacts (FAO 2010d). However, the major limitation to this approach is that the permanence of containment technology is still uncertain (FAO 2010d, Lorentz and Minogue 2015). An additional obstacle to this solution is that FSC regulations currently expressly forbid any use of GM trees (Strauss et al. 2004, Brunner et al. 2007, Meirmans et al. 2010, Richardson 2011). In addition, some invasive alien tree species (*Ailanthus altissima*, *Populus* spp., *Robinia pseudoacacia*) also spread by vegetative propagation. Plantations of non-native species of *Acacia*, *Eucalyptus* and *Pinus* and have typically been relatively free of pest problems during the early years of establishment due to a separation from their natural enemies. This situation has however changed dramatically recently, as pests are accidentally introduced, but also as native organisms have started to infect and infest alien trees (Payn et al. 2015, Wingfield et al. 2015).

### 2.2 Adopt good nursery practices.

Best-practice methods relating to species and provenances of seed (Karlman 2001), seedling production, weed, pest and disease control should be adopted (FAO 2011). Weeds should be identified, recorded, and eradicated where possible, before planting. The EPPO standard PP 1/141 (3) describes the conduct of trials for the efficacy evaluation of herbicides in tree and shrub nurseries including nurseries within forest stands (EPPO 2009). Nurseries can act as important sources of alien species into plantation sites. Many forest pests, both insects and pathogens, have also entered new lands via nursery stock. Nurseries have a fundamental role in promoting the use of native trees, stocking suitable provenances, and proposing alternative native tree species in place of alien species (*principle* 2.1).

### 2.3 Modify plantation practices to reduce problems with invasive alien tree species.

Containment of alien trees to areas set aside for their cultivation must become an integral part of silviculture and must be incorporated in best-management practice guidelines and certification schemes (e.g., Engelmark et al. 2001, Richardson and Rejmánek 2004, Richardson 2011, Dodet and Collet 2012, Felton et al. 2013). Silvicultural practices can either enhance or hamper biological invasions (e.g. Sitzia et al. 2016).

Wingfield et al. (2015) have called for a global strategy to promote the health and sustainability of planted forests. Practices to reduce problems with invasive forestry trees need to be incorporated in such a strategy.

Decision-support schemes and research findings should be applied to identify the most appropriate sites for cultivation within landscapes; biodiversity issues and ecosystem services must be always considered in plantation design and site selection (e.g., Veldman et al. 2015). While some of these rules can be considered of general utility, some other good practices refer to specific alien tree species and aim to mitigate specific impacts, as in the case of the practices suggested by Finch and Szumelda (2007) for Douglas fir in temperate forests of Central and Western Europe, by Ledgard (2002) for the same species in New Zealand, by Engelmark et al. (2001) for lodgepole pine in Sweden, by Rejmánek and Richardson (2011), Calviño-Cancela and Rubido-Bará (2013), Lorentz and Minogue (2015) for *Eucalyptus*.

To avoid natural spread, eucalypts should not be planted near rivers and streams. Temporarily flooded or eroded banks are suitable habitats for spontaneous establishment of their seedlings. Moreover, their seeds can be dispersed over long distances by running water (Lorentz and Minogue 2015). Calviño-Cancela and Rubido-Bará (2013) suggest the establishment of a safety belt around eucalypt plantations in Spain to reduce eucalypt spread from plantations in the absence of fire. This measure would require the elimination of all newly recruited individuals in this safety belt (e.g. a 15-m wide belt could reduce the probability of eucalypt spread in more than 95%) before they mature and start producing their own seeds, thus hindering the advance of the front line of invasion. For this purpose, Calviño-Cancela and Rubido-Bará (2013) recommend interventions at 1-2-year intervals to uproot saplings and resprouts. Their results refer to a situation without fire. Fire stimulates regeneration (Gill 1997) and could increase dispersal distances, so that additional measures would probably be needed to control *E. globulus* spread after fires. In addition, Catry et al. (2015) suggest planting sterile *Eucalyptus* trees and prioritizing control in regions with the highest probabilities of recruitment.

### 2.4 Revise general land management practices in landscapes with planted forests.

In many cases, options exist for managing plantations of non-native trees and adjoining areas (invaded or potentially invasible) by manipulating disturbance regimes (e.g., fire cycles, grazing levels) to impede invasion (e.g. van Wilgen et al. 1994). The management of planted forests should also promote biodiversity (e.g., Zapponi et al. 2014), both within the planted forest itself and in areas of natural forest that are retained within the planted forest landscape (e.g. establish planted forests on degraded sites and retain areas of high biodiversity value protected) as recommended by the Secretariat of the Convention on Biological Diversity (2009). Managers can modify the silviculture of plantations in other ways to enhance diversity. For example, small variations in the timing and type of site preparation can affect the development and composition of the understory (Carnus et al. 2006).

Specific attention and management practices should be followed in the case of genetically modified tree plantations, such as hybrid or transgenic poplars and conifers (Engelmark et al. 2001, FAO 2006, 2010c, 2011, Brunner et al. 2007, Strauss et al. 2009, Di Fazio et al. 2012, Häggman et al. 2013). In Canada and many other countries, regulatory guidelines have been created regarding the introduction of such plants with novel traits (which in Canadian regulation includes alien species and transgenics; Bonfils 2006, Meirmans et al. 2010).

Forest plantation owners should be aware of those forestry activities that favour the spread of invasive alien tree species (Sitzia et al. 2016). For example, coppicing was found to be a driver of invasions by *Ailanthus altissima* and *Robinia pseudoacacia* in South Tyrol, Northern Italy. Radtke et al. (2013) concluded that currently applied coppice management, involving repeated clear cuttings every 20–30 years, favours the spread of both invasive tree species. They suggested an adaptation of the management system to avoid further invasion.

The risk of promoting the spread of fire-tolerant or pyrophytic alien trees must be taken into account when planning the use of prescribed burning in plantation forests. For example, the resprouting ability and pyrophytic seeds of *Acacia dealbata* allows this species to establish after fires in the northwestern Iberian Peninsula (Sanz Elorza et al. 2004, González-Muñoz et al. 2011). Maringer et al. (2012) describe the colonization of burned patches by *Ailanthus altissima* and *Robinia pseudoacacia* on the southern slopes of the Alps. Todorović et al. (2010) suggest that the post-fire invasive potential of *Pauwlonia tomentosa* can, at least partly, be explained at the germination level.

Finally, tailored management practices should be followed in plantations for bioenergy production (SRF/SRC) to ensure the careful choice of new planting sites for favouring biodiversity (Weih 2008, Framstad 2009), protecting hydrology (Christen and Dalgaard 2012), conserving landscape values and for the restoration of the site after the cultivation cycle (Hardcastle 2006, McKay 2011, Neary 2013, Caplat et al. 2014). In Austria 10 principles for short-rotation forestry systems, from the viewpoint of nature protection and environment, have been declared since 1998 (Trinkaus 1998). Principle 2 states that " … Indigenous plants should play an important part, because non-indigenous plants (e.g., *Robinia pseudoacacia* and *Ailanthus altissima*) often show an undesirable tendency to spread".

### 2.5 Adopt good practices for harvesting and transport of timber.

Harvesting activities such as road construction and movement of harvesting equipment are well known to disperse seeds or propagules of invasive species and to cause disturbances that help them to flourish (Kaplan et al. 2014).

Harvesting and transport of non-native trees should be planned, supervised and undertaken by appropriately trained personnel. Good practices should minimise the risk of further spread of invasive alien species, and the disturbance that could promote the establishment of other invaders. Careful planning will substantially reduce the road

density required within a forest, the number of temporary timber extraction tracks, and minimise adverse environmental impacts such as soil disturbance, compaction and erosion. Whenever feasible, alien trees should be harvested individually or in small groups, to limit the risk of creating suitable habitats for other invaders.

Forest personnel should be trained to recognize and report unusual pests and symptoms of diseased or infested trees, and to carry out practices that reduce the risk of pest and weeds populations moving to other locations. Personnel should wear outer layers of clothing and footwear that are not "seed friendly" to minimise the risk of spreading alien species accidentally.

### 2.6 Adopt good practices for habitat restoration.

Specific guidelines for the restoration of sites previously occupied by plantations with alien trees need to be adopted. Restoration objectives can be broadly classified into overarching strategies, such as rehabilitation, reconstruction, reclamation, and replacement (see Stanturf et al. 2014). Only native plant species should be used for habitat restoration in areas affected by plantations. Native tree species can grow in the understory of alien tree plantations established for timber production or a variety of other forestry purposes. Not all alien tree plantations develop species-rich understories; some remain as tree monocultures. Low light intensity below the canopy, distance to seed sources, inhospitability to seed dispersers, poor soil or litter conditions for seed germination or seedling growth, intensive root competition with the planted alien species, chemical inhibition and other forms of allelopathy and plant interactions, plantation design, or periodic disturbances by organisms or any external factor are likely causes that require careful consideration (Lugo 1997).

Guidelines for restoration of sites previously occupied by plantations of *Robinia pseudoacacia* have been produced in the Piedmont region of Italy. Sturgess and Atkinson (1993) suggested management strategies for the restoration of near-natural sand-dune habitats following the clearfelling of *Pinus* plantations in Britain, and Brown et al. (2015) proposed approaches for plantations of alien conifers on ancient woodland sites. Szitár et al. (2014) assessed the recovery of open and closed grasslands over five years following the removal of alien pine plantations through burning at an inland sand dune system in Hungary. Arévalo and Fernández-Palacios (2005) proposed continuous elimination of *Pinus radiata* and enrichment with new individuals of *P. canariensis* on Tenerife, Canary Islands (Spain). Hughes (2003) and Moss and Monstadt (2008) propose management guidelines for the restoration of floodplain forests in Europe.

### 3.1 Promote and implement early detection & rapid response programmes.

Early detection and initiation of management can make the difference between being able to employ feasible offensive strategies (eradication) and facing the necessity of retreating

to a more expensive defensive strategy (mitigation, containment, etc.). Proactive measures to reduce the chances of invasions and to deal with problems at an early stage must be incorporated in standard silvicultural practices. Developing watch lists of possible new tree invaders can also enable more rapid reaction (Richardson 2011, Faulkner et al. 2014).

The relatively long initial lag phase between introduction and naturalization/invasion and slow dynamics observed in many forest plantation tree species compared with other plant species, offers opportunities to control the alien species while escaped populations are still small (Finnoff et al. 2007, Dodet and Collet 2012). Any signs of invasiveness reported inside the forest plantation or in its proximity should be carefully monitored so as to avoid serious problems developing.

Conifer wildings are relatively easy to control in the very early stage of invasion, as they are relatively easy to detect (most invasions are into grasslands and shrublands), and their direction of spread (downwind), and age when significant seed production begins (usually 10-15 years) is very predictable. There are therefore good opportunities to intercept the spread sequence very early in the cycle, and prevent wildings becoming dominant and uncontrollable outside the forest plantation (Froude 2011).

However, experience with introduced conifers in new environments indicates that spread events could begin at any time, even if little significant spread had been observed up to that time. Possible reasons could be synchronisation of all factors needed for successful spread (e.g. plentiful seed, low herbivores/ pathogens, good germination and seedling establishment conditions), arrival of suitable symbionts (notably mycorrhizae) to aid early establishment, and climatic change to conditions more suited to the planted alien trees (Despain 2001; Engelmark et al. 2001). Widespread natural establishment of *Eucalyptus globulus* plants in Portugal was recently documented by Águas et al. (2014) and Catry et al. (2015).

### 3.2 Establish or join a network of sentinel sites.

The idea of having a network of sentinel sites for monitoring or detecting biological changes or phenomena is not new and has been most widely applied to monitoring the spread of infectious diseases (e.g., Sserwanga et al. 2011, Vettraino et al. 2015). This approach has also been advocated for detecting the arrival or initiation of spread of alien species (Richardson and Rejmánek 2004, Meyerson and Mooney 2007) and a national system for detecting emerging plant invasions was proposed in the United States (Westbrooks 2003), but has yet to be implemented.

Plantations of alien trees should form part of any sentinel site network for monitoring alien tree invasions. Other areas that are likely to act as sources of propagules and sites of entry for new invasions are areas of human habitation where gardens have been established, especially where these adjoin natural vegetation (Alston and Richardson 2006), and experimental plantings, arboreta or botanical gardens containing alien tree species. Visser et al. (2014) have shown that Google Earth can be an useful tool for establishing a global sentinel site network for tree invasions, because imagery is con-

tinuously being updated, is free and low-tech. The wide availability of Google Earth could enable monitoring of this network of sentinel sites as part of "citizen science" efforts which could help to: (1) identify emerging trends in tree invasions; (2) provide valuable locality information for particular alien tree species; (3) monitor changes in alien tree species abundance and distribution over time; (4) help ensure legislative compliance of land managers and plantation owners; and (5) track management efforts over time (Visser et al. 2014). Besides such sentinel sites, new technologies such as smartphone application software (apps) are increasingly used to reach a wider audience on the subject of invasive alien species and to involve the public in recording them (Adriaens et al. 2015).

### 4.1 Engage with the public on the risks posed by invasive alien trees, their impacts and on options for management.

The general public is one of the most important stakeholder groups in national issues of forests and forestry (e.g., Hemström et al. 2014). The active and informed participation of communities and stakeholders affected by plantation forest management decisions is critical for the credibility and sustainability of management processes. Social learning (Leys and Vanclay 2011), public awareness-raising and communication activities are crucial for informing and educating the public, thereby allowing them to more effectively participate in decision making. Public participation GIS and related methods can be effectively used for decision-making processes related to planted forests (Brown et al. 2015). Public support for control efforts directed at invasive alien trees must be sought through carefully planned, long-term outreach initiatives involving, among other things, meetings with stakeholders, local village leadership, employment of villagers from areas adjacent to invaded sites, and the effective use of media outlets (Andreu et al. 2009, McNeely 2001, Marchante et al. 2010, Schreck Reis et al. 2011). Forestry has become more complex over the years. This form of land use now impacts on a wider stratum of people and environments than ever before, and is subject to many social and environmental demands.

Furthermore, an increasing number of tourists are interested not only in experiencing unique natural and cultural environments and forest landscapes but also in learning more about them. Forest-based tours are an ideal opportunity to share information about different types of forest environments, native and non-native tree species, restoration actions, wildlife and landscapes, and how they function.

### 5.1 Consider developing research activities on invasive alien trees species and becoming involved in collaborative research projects at national and regional levels.

Invasion biology is a complex multidisciplinary field and public and private plantations of alien trees are good places to conduct research on topics such as the spread, control,

management and risks posed by invasive alien trees in collaboration with national or local environment agencies, research centres and appropriate regional or European bodies. Great Britain, for instance, with its long history of tree introductions and large plantings of many alien species (e.g. *Picea sitchensis*, the commonest British tree, Peterken 2001), is a good natural laboratory for studies of the determinants of naturalization and invasion in conifers and its consequences (Richardson and Rejmánek 2004). It would be very informative to revisit as many sites as possible in Europe where many alien tree species were planted long ago, e.g. the experimental plantings of many conifers in Italy (Nocentini 2010), Portugal and Spain, and abandoned plantations (Richardson and Rejmánek 2004). The exchange of information on the management experiences is another key aspect.

### 5.2 Take global change trends into consideration.

Forest management and conservation are expected to be strongly influenced by global change. Besides forest species, strategies and references for environmental management and conservation will be affected by global change trends (Jackson et al. 2005, Aitken et al. 2008, Canadell and Raupach 2008, Diaz et al. 2009, Heller and Zavaleta 2009, Thompson et al. 2009, Strassburg et al. 2010, Milad et al. 2013). For example, rapidly changing climate patterns, altered disturbance and nutrient regimes, and increased fragmentation are likely to favour the expansion of pine invasions worldwide (e.g., Higgins and Richardson 1999, Richardson and Rejmánek 2004).

Bernier and Schoene (2009) propose three possible approaches for adapting forests to climate change: no intervention, reactive adaptation and planned adaptation. Unfortunately, most current management belongs to the first or at best to the second category. No intervention means business as usual, with tree species and site selection, management targets and practices based on the premise that the planted forest will adapt more or less as it has in the past. Reactive adaptation is action taken after the fact. Planned adaptation, on the other hand, involves redefining planted forest goals and practices in advance in view of climate change-related risks and uncertainties.

In planted forest, climate change could affect the dynamics of alien tree invasions in many interacting ways, for example by: (a) causing modification in the native ecosystems, promoting range changes, naturalisation and spread of both native and alien trees (e.g., Iverson et al. 2008, McKenney et al. 2011); (b) favouring individual traits of particular alien trees (e.g. Capdevila-Argüelles and Zilletti 2008, Kawaletz et al. 2013, Castro-Díez et al. 2014); and (c) modifying introduction pathways and promoting increased use of certain alien tree taxa (Courbet et al. 2012, Lindenmayer et al. 2012), including a process of re-thinking the importance of the "always choosing native species" principle. Managed relocation has been proposed as a means of maintaining forest productivity, health, and ecosystem services under rapid climate change (e.g., Schwartz et al. 2012). Discussion is intensifying in many countries on whether and, if so, then to what extent, alien tree species should be used for afforesta-

tion, especially when native species are no longer able to fulfil essential forest functions. For example, in this regard, for the first time the growth potential of *Cedrus libani* was evaluated under climatic conditions in Central Europe (Bayreuth, Germany) by Messinger et al. (2015).

Finally, it is important to incorporate climate change into risk models for an anticipatory evaluation of scenarios for invasiveness of alien trees. Risk maps that incorporate the effects of climate change should help land managers and forest stakeholders with longer-term planning activities. Management plans of nature reserves should incorporate changes to invasion risk driven by global warming more explicitly. For example, Kleinbauer et al. (2010) suggest that the area suitable for invasions by *Robinia pseudoacacia* will increase considerably in Europe under a warmer climate. They argue that management plans for European nature reserves should incorporate such changes to invasion risk by species such as this one more explicitly. Reducing propagule pressure by avoiding plantings of *R. pseudoacacia* close to protected areas and sensitive habitats would be a simple way of reducing the risk of further invasions of this species under future climates. On the contrary, González-Muñoz et al. (2014) found no evidence that climate change will cause substantial changes to the invasion dynamics of *A. dealbata* in Spain.

## Conclusions

The *Code of Conduct on Planted Forest and Invasive Alien Trees* is a voluntary tool and it does not replace any statutory requirements under international or national legislation. It should be seen as complementary to them and as a soft-law standard (Hickey et al. 2006, Terpan 2015). Its principles should be considered in forest management to mitigate risks related to use of invasive alien trees in plantations. Wood is often the most important product of plantations but non-timber forest products and the provision of ecosystem services also need to be considered in sustainable silvicultural systems. Long generation times of forest trees and rotation cycles often preclude the rapid adoption of new management regimes over large forested areas. Therefore, both the application of the suggested principles and the monitoring of the effects will need to be systematically phased in.

Alien tree invasions are currently more widespread outside Europe, especially in the southern hemisphere. New insights on the factors that determine invasiveness and on ways of managing tree invasions are emerging rapidly (Richardson et al. 2014). Although socio-political factors in Europe demand unique approaches for dealing with tree invasions, developments from elsewhere, especially regarding ways of dealing with conflicts of interests and effective engagement with multiple stakeholders, provide many useful lessons. For these reasons, and also because the role of "forestry in the Anthropocene" in general is being actively debated (e.g. Lugo 2015), the Code will need to be revised regularly.

Invasion biology is a complex multidisciplinary field and public and private plantations of alien trees are good places to conduct research on topics such as the spread,

control, management and risks posed by invasive alien trees in collaboration with national or local environment agencies, research centres and appropriate regional or European bodies. Key priorities for further research to enhance our ability to manage tree invasions more effectively include: (1) better understanding of the edaphic, climactic anthropogenic and biotic factors that cause some tree invasions to succeed and others to fail; (2) improved schemes of risk assessment for alien trees (including transgenic trees) that could reliably take into account impacts on ecosystem services and effect of climate change on the invasiveness of alien trees in different biogeographical regions; (3) novel and improved methods for early detection & rapid response; (4) tailored decision-support schemes, adaptive strategies and silvicultural systems for the management of new and existing plantations with alien trees and for the restoration of sites after a change of the land use and in degraded areas; (5) management strategies and tools for novel forest ecosystem dominated by alien species escaped from cultivation (Lugo 2015); (6) how to better instigate behaviour change in owners and stakeholders to enable and encourage a more co-operative approach to the management of planted forests and build consensus with the public on controversial methods and species.

Plantations and restored forest ecosystems are a key strategy not only for tackling climate change, biodiversity loss and desertification, but can also yield products and services that support local people's livelihoods (Chazdon 2008). At the 2104 UN Climate Summit, an unprecedented alliance of governments, companies, and civil society issued the New York Declaration on Forests, which aims to restore 350 million hectares of deforested and degraded landscapes by 2030. This pledge complements and extends the Bonn Challenge, an existing global effort to restore 150 million hectares by 2020, facilitating the implementation of several existing international commitments that require restoration, including the CBD Aichi Target 15, the UNFCCC REDD+ goal and the Rio+20 land degradation target.

In the past, many restoration efforts have failed for a variety of reasons. Success in restoration initiatives should not be reported and measured simply as number of trees or hectares planted, as these measures do not necessarily imply long-term success and the conservation or restoration of ecosystem services. Of course many factors can influence whether restoration initiatives will successfully achieve ecological and livelihood-related goals, starting with the right selection of species, provenances and genotypes. Importantly, the 12th Conference of Parties to the CBD adopted a decision in October 2014 that urged parties "to give due attention to both native species and genetic diversity in conservation and restoration activities, while avoiding the introduction and preventing the spread of invasive alien species (Decision XII/19, 17 October 2014).

We propose that the principles of the *Code of Conduct on Planted Forest and Invasive Alien Trees* could be considered as the foundation for a global strategy of planted forest, forest management and restoration to mitigate the risks related to use of invasive alien trees in forestry. Dedicated research, innovative solutions and a better-coordinated global approach are needed to face this challenge.

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## Supplementary material 1

**Supplementary tables**

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Data type: tables

Explanation note: **Table 1.** Examples of specific plantation practices aimed at reducing problems with invasive alien tree species. Some of these rules can be considered of general utility, whereas others refer to specific alien tree species and aim to mitigate specific impacts. **Table 2.** The fifty alien trees most frequently listed (with different rankings) in European countries